The Symbol Synchronizer Assembly

M. J. Galitzen
DSN Data Systems Section

The Symbol Synchronizer Assembly improvement effort is directed at three goals: to increase the maintainability, operability and reliability within the analog-to-digital conversion portion of the SSA's phase lock loop and telemetry data extraction channels. In achieving these goals we propose to replace obsolete, nonmaintainable and unreliable electronic and mechanical devices with readily available electronic equipment of modular solid state design.

I. Introduction

The primary function of the Symbol Synchronizer Assembly (SSA) is to phase lock a local data clock with a demodulated telemetry data stream. This function is accomplished by means of a hybrid analog/digital phase-locked-loop. The SSA's phase-locked local data clock enables the SSA to perform telemetry data bit detection for encoded telemetry and symbol estimates for coded telemetry. This information is then transferred to computers or external decoders for further processing. The SSA's were implemented in the Deep Space Stations starting in 1970. While still performing the basic functions, recent failure analysis has shown that the SSA's are experiencing a higher than desired failure rate. Analysis of the failure reports showed three assemblies within the SSA's which, because of age and commercial nonavailability, are becoming increasingly difficult to maintain and calibrate at the Deep Space Network maintenance depot. These same three equipment areas can become a major DSN station reliability problem if corrective action is not taken. The specific SSA hardware areas in question are listed below:

(1) The coaxial switch assembly.

(2) The loop integrator board and assembly.

(3) The analog-to-digital – digital-to-analog (A/D-D/A) converter assembly.

These three assemblies make up the input signal selection matrix, the analog telemetry signal processing channels and the analog-to-digital transition A/D-D/A equipment. It is within these three assemblies that the transition from the analog (raw telemetry data) to the digital (digitized telemetry) is accomplished.

II. Existing Telemetry Subsystem

Figure 1 shows a fundamental block diagram of the telemetry data path from a spacecraft to the telemetry subsystem. An overview of this system will place the telemetry system in perspective with respect to the spacecraft data reception path and also show the importance of the areas that we propose to upgrade. The spacecraft transmits modulated radio frequency signals to the DSN antennas. This signal is processed and down-converted in frequency within the receiver subsystem. The Subcarrier Demodulator Assembly (SDA) extracts the raw telemetry data at its base rates of 5.6 to 250,000 symbols per second.

The SDA output level is a nominal ±141 millivolts peak signal in noise. The telemetry input channels which process these signals are located within the SSA. The SSA is required to process and extract telemetry from an SDA signal with a signal-to-noise ratio as low as −5 dB. Figure 2 shows the front end of the telemetry subsystem and emphasizes the three assemblies within the SSA that were covered in the introduction. Problems within these assemblies will be explained next.

The coaxial switches within the present SSA Interface Assembly receive four different inputs. These coaxial switches then provide isolation and data paths to the SSA logic. There are four coaxial switches associated with this function. The four inputs are typically comprised of three SDA inputs and a test input, although any input port can receive and process telemetry data. Control of the 4 × 1 selection matrix is controlled by the Telemetry Subsystem Assembly (TPA) computer through the SSA interface logic.

Problems associated with these coaxial switches center in their mechanical contacts. Typical failure mode is an intermittent contact closure. Location and removal of the intermittent coaxial switches from the SSA rack is difficult. Physically, the coaxial switches are located in the bottom rear portion of an SSA equipment rack. Removal requires station floor board removal for access to the rack bottom. Also numerous cables must be disconnected before the coaxial switches can be removed from inside their mounting assembly. Besides these difficulties, the cost of these coaxial switches is now approximately 4 times the original cost. Replacement cost of a single coaxial switch is now approaching $1000 from an initial $250 cost. The order lead time for these units is now several months.

The Loop Integrator Assembly (LIA) and its circuit board will be the next SSA problem area covered. It is shown in Fig. 2 that the LIA receives its inputs from the coaxial switches. The LIA is located in the upper front portion of the SSA equipment rack. The long cable path from the coaxial switches to the Integrators induces noise into the telemetry.

The Loop Integrator provides precision amplification, signal integration and telemetry bit transition detection within the noise bandwidth of the telemetry channel. The SSA detects and phase locks the station data clock to the spacecraft data clock. In this manner the spacecraft data can be detected, formatted and processed. A weakness in this system is that all data and phase processing is accomplished on a large printed circuit board. Failure in one channel of this board requires removal of all analog circuitry within the SSA. Therefore, when this board is replaced, all analog adjustments must be redone to ensure proper operation. These are critical adjustments that consume time. They must be made after the board has reached thermal stability, which can take hours.

Repair of the Loop Integrator board is also difficult as these boards have three layers. This means that there are three circuit etches, one on each side of the board and one centered (pancaked between the two outer layers). Because this is a multichannel board, the component density is quite high and the etch is complex. Repair of board circuitry involved in the center etch is very difficult. In some cases the board has to be cut, new components soldered in, and new epoxy applied to secure the repair. During this process, boards have been destroyed or after repair have had trouble meeting minimum Q.A. standards. There is a tendency to expend additional cost and efforts to requalify these marginal boards.

The A/D-D/A Converter Assembly is the last SSA area in which corrective measures are recommended. Figure 2 shows that the A/D-D/A Converter Assembly is driven by the LIA, which is in turn driven by the SDA through the coaxial switches.

The A/D-D/A Assembly consists of two identical 12-bit analog-to-digital converters (A/D's), one 5-bit A/D, and one 12-bit digital-to-analog (D/A) converter. The two 12-bit A/D's digitize the telemetry input from the integrate and dump circuits of the LIA. The science and engineering telemetry is then extracted from this 12-bit conversion. In addition, these 12 A/D bits provide the basis for determining the SSA loop lock within the TPA computers. The 5-bit converter is used in the SSA phase-lock-loop to digitize the telemetry signal and drive the phase-lock-loop's logic to minimize the loop's lock error at a telemetry data transition. The 12-bit D/A converter receives and converts the accumulated error of the 5-bit A/D phase channels. The 12-bit D/A then provides an analog voltage which is used to drive the SSA frequency synthesizer.

It is through this process that the phase-lock-loop is closed and the output frequency of the synthesizer is kept in phase with the spacecraft telemetry signal data transitions. The synthesized frequency is then used as a data rate to synchronize the SSA to the spacecraft.

The maintenance and repair to the approximately 10-year-old A/D-D/A converter assembly is a problem, as the manufacturer has been out of business for approximately four years. The assembly consists of 31 circuit boards containing discrete components, none of which are supported by a manufacturer. In addition to the complexity and card count, this converter is difficult to calibrate. Without factory support the DSN maintenance depot must maintain the capability to repair and calibrate the unit, which is becoming more difficult with time.

III. SSA Prototype Upgrade Assembly

This section will present information about a prototype SSA upgrade assembly which has been assembled and tested within three different SSA's. Figure 3 is a block diagram of the prototype assembly, which functionally performs the same telemetry process that is accomplished in the present SSA (Fig. 1). In Fig. 3, the functions are divided into seven functional blocks from the three functional blocks in Fig. 1. Seven circuit cards are used to implement the design in Fig. 3. These cards mount in a 5-1/4-inch front panel chassis along with ±15-volt and +5-volt power supplies. The chassis back panel contains a fan, AC power plug and fuse, 4 multipin connectors, and 6 coaxial connectors. The multipin connectors provide timing, control, and status signals used within the prototype assembly. These connectors will connect to the existing SSA harness without modification to the SSA.

The input telemetry or test inputs are switched through four 16-pin analog switches, which provide isolation, loading, and the status functions now performed by the SSA mechanical coaxial switches. These analog switches are controlled by the TPA computer through the SSA computer status and monitor board within the prototype assembly. The selected telemetry data is then reamplified in the gain select amplifiers, which are on the same card as the four analog switches. The output of this card then becomes the input to the two identical 12-bit A and B data channel cards and the 5-bit phase channel card. The two data channels contain an integrator, sample and hold amplifier circuit, and a 12-bit A/D converter. The outputs of these converters are switched through the multiplex card and sent as the digitized telemetry to the SSA and TPA.

The 5-bit phase card contains an integrator, sample-and-hold amplifier, zero crossing detector circuit, and 8-bit A/D converter. Only 5 of the 8 bits are used in the prototype assembly. These 5 bits are processed within the SSA's phase error logic. The zero crossing detector detects the telemetry data's edge transition. This transition is used in the SSA's phase and data processing logic.

The 12 bit D/A and pulse shaping card receives digital phase and clock signals from the SSA. The 12 bits of phase information are converted to an analog voltage which is proportional to the phase error between the telemetry signal and the DSN station clock. This error voltage is amplified in the gain selector logic card and then fed back as the phase-lock-loop error voltage to the SSA's frequency synthesizer. The synthesizer output is used to clock the SSA logic and close the phase-lock-loop. The D/A card also contains pulse shaping and timing interface circuits required to interface the SSA to the prototype logic. The status and monitor card is the seventh card needed to implement Fig. 3's design. This card provides a control interface point for signal status and prototype monitoring required by the SSA and TPA.

Many of the reasons for going to this modular seven card design have been covered. This design combines the three functional blocks listed in Part II into one chassis. The switching, data processing, and A/D-D/A conversion process is then divided into functional blocks. The seven functions are then implemented on separate circuit cards of simple construction, which reduces the number of descrete components used. The present SSA A/D converter requires 31 circuit cards. This same function is accomplished on only part of each of the two data channel cards and the phase channel card. The reduced complexity of the A/D-D/A converter assembly will greatly shorten the calibration time. The modern modular replacement A/D converters can be calibrated in approximately one hour. A technician is typically required to adjust two potentiometers, which set the A/D's zero reference and gain. The D/A requires two external adjustments of equal simplicity. The A/D and D/A modules are presently being manufactured and are under GSA contract. The problem with the SSA multichannel three-layer analog board has been corrected in the seven-board prototype as the new cards are of two layer construction.

Table 1 lists the electronic components required for the prototype assembly vs the equivalent operational SSA assembly. The prototype assembly has approximately one-ninth the number of parts required in the SSA. The prototype assembly has no mechanical parts such as the 13 relays and 4 coaxial relays used in the SSA.

IV. SSA Prototype Upgrade Testing

The telemetry system within the JPL Compatibility Test Areas-21 (CTA-21) has been used to test and evaluate the prototype assembly. The telemetry system at CTA-21 contains three SSA's. In some of the testing, an operational SSA was driven by a simulated telemetry data input from an SDA. The output of the SDA is set to give a specific SSA signal-to-noise ratio and symbol error rate. The operational SSA's output is then compared to the theoretical probability of performance. For some of the data points the prototype assembly was then connected to the SDA and SSA. The constant SDA output was then processed as an input to the prototype assembly. Comparison of SSA vs prototype assembly data is shown in

Table 2. Comparison data was taken at 250, 230.4, 100.0, 50.0, 28.0, 13.5, 12.5, and 1K symbols per second. Many additional data points for the prototype assembly were taken and are shown on Table 2. This data demonstrates that there is a good operational comparison between the prototype assembly and an operational SSA.

Further evaluation of the prototype assembly is being performed at CTA-21. The prototype assembly is now connected to one of the operational SSA's. This temporary configuration will exist for approximately a one-month evaluation period. During this time we will evaluate the prototype semi-operational performance.

Table 1. Equivalent SSA vs prototype parts count

	Upgraded assembly	Present SSA assembly
Part description		
1. Components, resistors, capacitors, transistors, integrated circuits, and diodes	395	3768
2. Relays	None	13
3. Coaxial relays	None	4
4. Power supplies	2 ±15, +5 Vdc	6 +15,−15,+25,−25,+5,+8 Vdc
5. Adjustment potentiometer	19	53
6. Operational amplifiers	10	6
Total: all components	427	3850

Table 2. SSA vs upgrade assembly symbol error rate signal-to-noise data

Symbol data rate	Data coding	Prototype SNR(dB)	Prototype SER(%)	SSA SNR(dB)	SSA SER(%)
8 Hz	Uncoded	7.04	0.07		
100 Hz	Uncoded	3.49	1.56		
1.00 kHz	Uncoded	−0.37	8.84	−0.33	8.29
10.00 kHz	Uncoded	−2.93	16.02		
12.5 kHz	Coded	0.95	5.69	0.62	6.0
13.5 kHz	Uncoded	−4.05	18.92	−3.79	18.52
18.0 kHz	Uncoded	0.29	7.22		
22.0 kHz	Uncoded	0.27	7.14		
28.0 kHz	Uncoded	−1.54	11.81	−1.44	11.69
44.0 kHz	Coded	−1.20	11.31		
50.0 kHz	Coded	0.66	6.41	0.91	6.44
56.0 kHz	Coded	0.84	5.99		
70.0 kHz	Coded	−4.45	20.15		
80.0 kHz	Coded	0.76	6.0		
100.0 kHz	Coded	0.62	6.28	0.77	6.06
130.0 kHz	Coded	0.97	5.66		
160.0 kHz	Coded	0.36	7.03		
200.0 kHz	Coded	0.76	6.06		
230.4 kHz	Coded	−0.13	8.02	−0.71	8.22
250.0 kHz	Coded	0.42	7.04	0.48	6.84
250.0 kHz	Coded	−5.89	23.36	−3.94	20.56[a]

[a]The operational SSA would not lock up at the −5.89 dB of the upgrade assembly. It was necessary to reduce the signal input SNR by 1.5 dB before the operational unit locked.

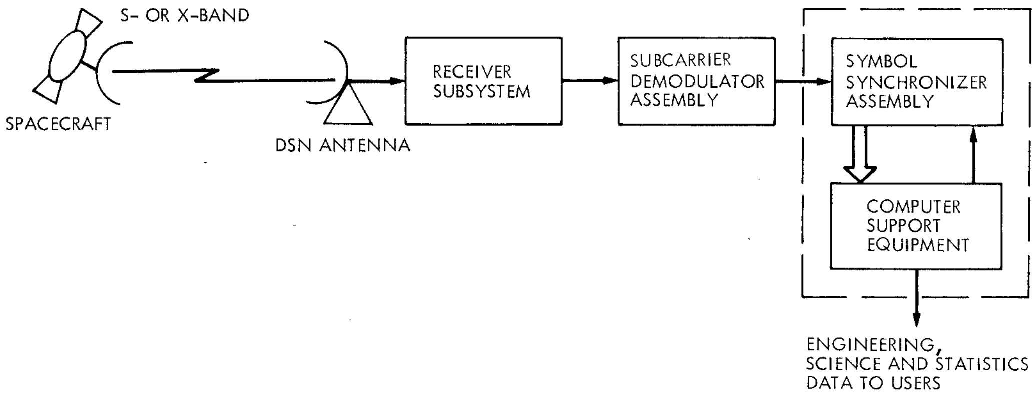

Fig. 1. Typical telemetry path at a DSN station

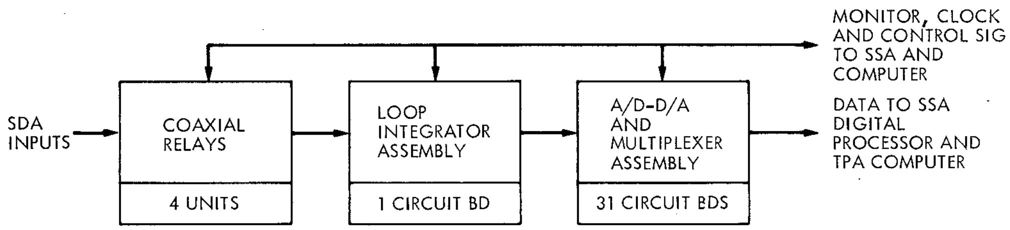

Fig. 2. Present SSA analog-to-digital conversion functional diagram

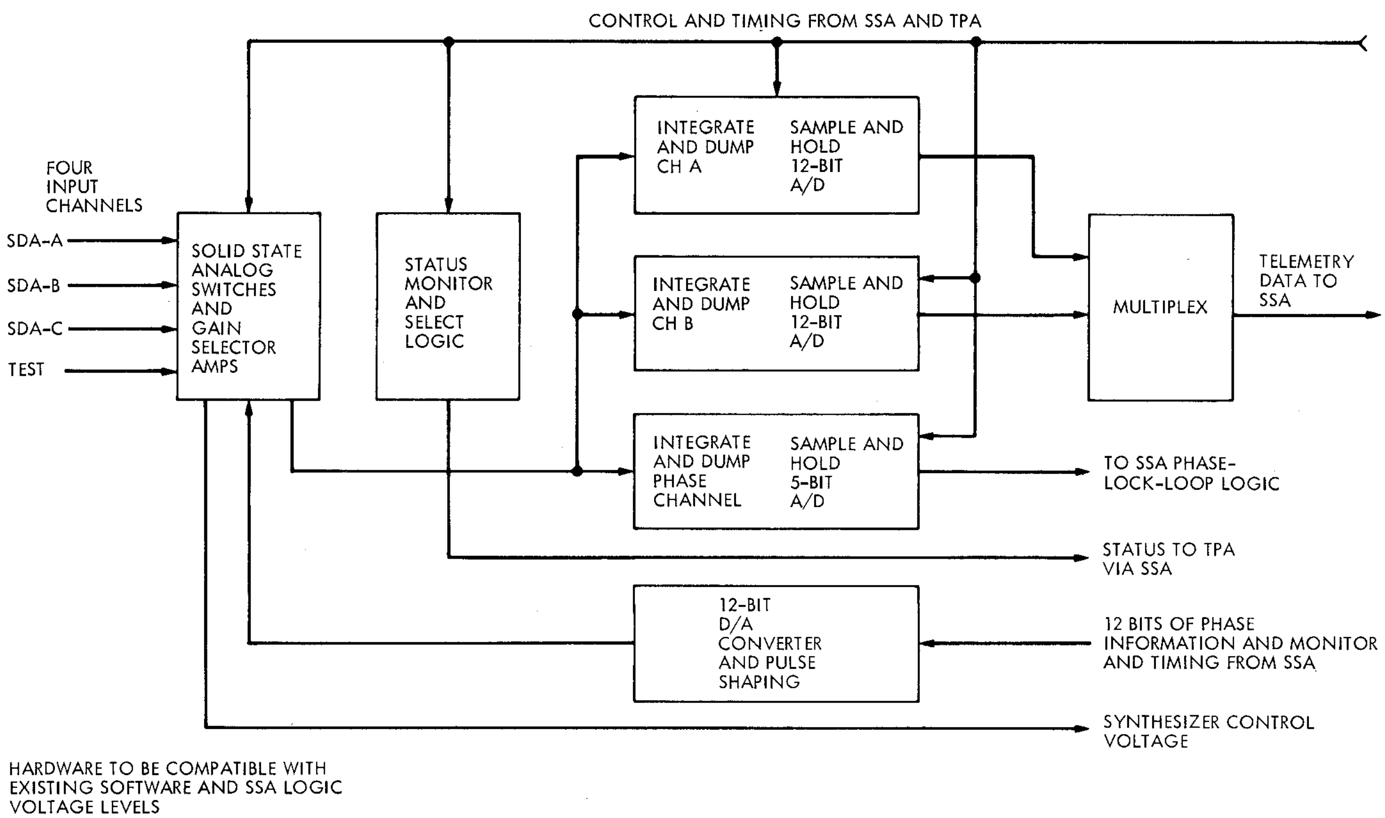

Fig. 3. SSA upgrade block diagram

NASA—JPL—Coml., L.A., Calif.